III-N UV Photonic Devices

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Principal Investigator(s): Debdeep Jena

User(s): Shyam Bharadwaj, Kevin Lee, Ryan Page, Jimy Encomendero

Affiliation(s): Electrical and Computer Engineering, Materials Science Engineering; Cornell University

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Contact: djena@cornell.edu, sb2347@cornell.edu, kl833@cornell.edu, rlp238@cornell.edu, jje64@cornell.edu

Primary CNF Tools Used: ABM contact aligner, electron-beam evaporators, Plasma-Therm PT770

Abstract:

Our research goal is to improve and fabricate deep ultraviolet (DUV) and visible photonic devices such as light-emitting diodes (LEDs) and laser diodes (LDs). We grow the semiconductor thin films by molecular beam epitaxy (MBE). The III-nitride material system is ideal for such devices due to its wide range of direct bandgaps. For deep UV devices, AlN, GaN and AlGaN are the typical materials. P-type transport is a major challenge in these materials; as such, we are focusing on improving this property through the use of InGaN contact layers and polarization-doped AlGaN cladding regions. The structure of the active region is also an important determinant of the external quantum efficiency (EQE) of the LEDs, so we are studying different active region thicknesses and compositions.

Summary of Research:

We grow UV LED structures by plasma-assisted MBE (PA-MBE). These LEDs are grown on metal organic chemical vapor deposition (MOCVD)-grown AlN on sapphire template substrates. One study we performed involved a comparison of AlGaN active region DUV LEDs to ultra-thin GaN active region ones. Ultra-thin GaN theoretically has a more favorable valence band alignment for light extraction, though AlGaN active regions can be grown thicker (resulting in a larger active volume — a larger region in which radiative recombination can occur) while still emitting at the same wavelength. The structures that were grown are shown in Figure 1.

Figure 1: Schematic structures of the UV LEDs grown in this study. On the left is the AlGaN active region LED, and on the right is the ultra-thin GaN active region LED. The AlGaN LED has one single quantum well, while the ultra thin GaN LED has 4 quantum wells separated by 2 nm AlN barriers.

After growing the LED structures, they were processed in the CNF using contact photolithography. Positive tone photoresist was spun onto samples for the device isolation step. After developing, individual devices were defined through ICP-RIE etching in the PT770 tool. The electron-beam evaporators were used to deposit metal contacts for probing.

After the LEDs were fabricated, the electrical and optical characteristics were measured through current-voltage (IV) and electroluminescence (EL) measurements. The results of these measurements are shown in Figure 2 (IV) and Figure 3 (EL).

It can be seen that that the electrical performance of the devices are fairly similar between the two structures, with current densities reaching ~ 500 A/cm^2 at 10V. The biggest difference in device performance can be seen in the EL results: the measured EL intensity for the device with an AlGaN active region is roughly 10x greater than the EL intensity from the device with GaN active region at the same current levels. This can be partly attributed to the difference in active volume: The AlGaN device active area is roughly 7x greater than the GaN device active area. More work is being performed to quantify the difference in emission properties (such as the angle- and polarization-resolved emission patterns) of the two active regions.

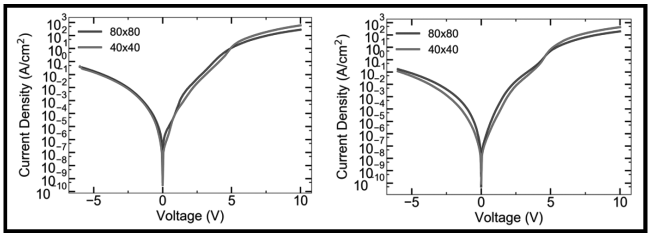

Figure 2: Log scale current-voltage characteristics of the two LEDs. The IV for the AlGaN active region LED is shown on the left, while the IV for GaN active region LED is on the right. Two different device areas were measured for each (80 × 80 square µm, and 40 × 40 square µm).

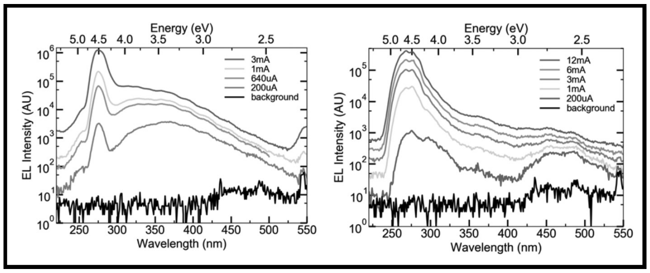

Figure 3: Log scale electroluminescence data for the two LEDs (AlGaN active region device on left, GaN active region device on the right). Both devices have emission peaks around 275 nm, though the AlGaN active region device has a larger broad peak around 375 nm (likely defect related). The AlGaN active region device has around 10x emission intensity as the GaN device for the samcurrent levels.